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INCINERATION AND ALTERNATIVE REFUSE DISPOSAL PROCESSES

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INCINERATION AND ALTERNATIVE REFUSE DISPOSAL PROCESSES

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SYNOPSIS

Various refuse collection and disposal systems are discussed.

Incineration as a refuse treatment method is critically evaluated - historically, economically, and technically.

The results of numerous refuse incineration studies are summarized.

Investigations on a system of high rate incineration for optimum volume reduction are reported upon.

The thermodynamic considerations of incinerator design and operation are reviewed.

The feasibility of employing a particular refuse disposal system or systems is controlled by three basic factors:

1. The refuse disposal system should be sanitary and enable a nuisance-free elimination of the waste materials. Flies and other insects, rodents, pathogenic organisms, ground water pollution and air pollution are examples of health hazards and nuisances resulting from inadequate refuse disposal.
2. Refuse handling and disposal should be functional and reasonably free from objectionable noise, odor, and effort, thereby commanding the positive support of the residents in a community.
3. The costs of refuse disposal should be economical within the limitations of high standards of sanitary and esthetic requirements. Figure 1 represents a simplified comparison of various waste collection and disposal systems.

Investigation

The authors were associated in 1951-52 with the University of California Sanitary Engineering Research Project studying municipal incineration. This and other investigations on incineration and alternative refuse disposal systems have been performed. (1,2,3,4,5,6,7,8). The purpose of this paper is to present a critical evaluation of data on this subject based upon:

1. A review of the literature.
2. A postal survey of cities utilizing incineration in the United States.

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3. Operational tests on two Southern California municipal incinerators to determine the feasibility of hi-rate burning.

4. Field studies on the construction and operational features of numerous plants located throughout the United States.

5. Investigations of other systems of refuse disposal.

Influences of Collection and Other Factors on Quantity of Refuse Disposal

The completeness and frequency of refuse collection influences the quantity and nature of waste materials. When all refuse is accepted for collection, maximum collections result. Similarly, semi-weekly collections of garbage, combustible, and non-combustible rubbish result in a larger quantity of refuse collected than when there is a less frequent collection service. Backyard, alley, or side of the house pickup tend to produce greater quantities of refuse than does curb placement for collection. Climate, topography, cultural, economic and social status of the inhabitants of a community, as well as a community's basic industrial activities, all exercise control over the quantity and nature of the refuse. Figure 2 presents a graphic summary of the quantities of refuse collected at several California communities. The type of collection vehicle affects the density and in some cases the moisture content of the collected refuse. Collection vehicles which compact the refuse tend to make it more difficult to burn or salvage, whereas closed collection vehicles protect rubbish from being wetted during collection.

Transfer Station

The transfer station is a flexible method for reducing the costs of transposting municipal refuse. A transfer station should be located in or near the city, convenient to collection routes. The station may be a simple elevated ramp or a depressed runway to provide a differential elevation for direct discharge of refuse from the collection truck to a transfer truck, or trailer, located at the lower elevation. The transfer station may also of necessity be an elaborate structure, such as the one located in the heart of Washington, D.C., (see Figure 3,) which provides completely enclosed, dust-free and odor-free transfer of garbage and ashes.

Once the refuse has been dumped into the large capacity truck, trailer, or semi-trailer, it can be hauled some 15 to 20 miles before the combined cost of transfer, haul, and landfill may exceed the cost of disposal at a central location through incineration. Economic comparisons between hauling to disposal sites in collection vehicles and hauling in transfer equipment are shown in Table 1.

Refuse Disposal Methods

Salvage - Wherever possible refuse should be reclaimed for re-use. Variations in the free market value of waste paper, cardboard, glass, and tin cans have in the past classified refuse salvage as a doubtful financial undertaking. However, many private operators successfully contract with cities, thereby directly reducing the amount of refuse to be disposed of.

Hog Feeding is a common method of raw garbage disposal in the United States. American public health authorities have correctly opposed unrestricted feeding of raw garbage to animals because of the danger of transmission of

TABLE 1

Comparison between Costs for Straight Haul and Transfer and Haul

Cost of One-Way Haul in Refuse Collection Trucks
Hauling Data from Three California Cities

City Designation	Time Spent at Landfill Site (Minutes)	Time Traveling to Landfill and Return (Minutes)	Round-trip in Miles	Minutes per Mile
A	27	23	4.8	4.8
B	8	17	4.2	4.0
C	10	62	24	2.6
Average	15	34	11	3.8

Assume: Average truck load = 2.75 tons
O&M plus amortization - collection truck = $1.25/hour
Labor: 1 driver = 1.50/hour
2 swampers at 1.25/hour = 2.50/hour
5.25/hour = $.0875/minute

Miles to Disposal Site (one-way)	Cost for Haul at $.0875 per Minute	Cost per Ton for 2.75 Ton load	NOTE: No charge made for time at disposal site as collection truck must also dump at transfer site when using transfer method.
1	$0.88	$0.32	
2	1.58	0.58	
3	2.28	0.83	
4	2.89	1.05	
5	3.32	1.21	
10	4.73	1.72	

Cost of One-Way Haul in Transfer Truck or Trailer

Assume: Cost of operating and amortizing transfer station = $0.40/ton
Average transfer truck or trailer load = 15 tons
O&M plus amortization for equipment = $2.50/hour
Labor: 1 driver = 1.50/hour
$4.00/hour = $.0667/min.
Average travel time = 3 minutes per mile (20 MPH)
Average time spent at site = 20 minutes

Miles to Disposal Site (One-Way)	Time for Round Trip (Minutes)	Cost for Haul at $.0667 per Min.	Cost for 20 Min. Period Dumping at Site	Total Cost for Haul and Dumping	Cost per Ton for Haul and Dumping	Cost of Transfer/ Ton	Total cost per Ton
1	6	.40	1.35	1.75	0.12	0.40	0.52
2	12	.80	1.35	2.15	0.14	0.40	0.54
3	18	1.20	1.35	2.55	0.17	0.40	0.57
4	24	1.60	1.35	2.95	0.20	0.40	0.60
5	30	2.00	1.35	3.35	0.22	0.40	0.62
10	60	4.00	1.35	5.35	0.36	0.40	0.76
15	90	6.00	1.35	7.35	0.49	0.40	0.89
20	120	8.00	1.35	9.35	0.62	0.40	1.02

trichinosis and vesicular exanthema. In England, the cooking of the garbage has proved to be a satisfactory method of preparing a homogenous and sanitary animal feed while still providing an economical means of disposing of garbage and conserving food values. Dessication of garbage is another possible method of sanitizing garbage and preparing a good animal feed. The effects of boiling citrus peels or other typical American food wastes in preparing a sterile animal feed remains to be determined.

Composting of refuse is now practiced on a wide scale in the Netherlands and other countries. This process has had little utilization for disposal of municipal and industrial refuse in the United States. However, additional experimental work will undoubtedly develop its feasibility.

Reduction of garbage for salvage of fats has been tried in several cities including Minneapolis, Rochester, Indianapolis, and Los Angeles. Over a considerable period of time, these reduction plants have proved financially unsatisfactory. In periods of economic stress, such as during a war, operations have been successful. Explosions are a frequent hazard at installations using solvent extractor units.

Land Disposal - Refuse have been economically disposed of by burial in soil. Historically, an open dump, accompanied by burning, was a most obvious means of refuse disposal. The obnoxious odors from the smouldering refuse and the large rodent and insect population supported by the dumps were highly undesirable. More recently, in certain areas, the use of controlled burning in which the refuse is carefully ignited, possibly with the use of auxiliary fuel and only when the wind is blowing the right direction, has proved satisfactory. The remaining residue and partially burned refuse should be thoroughly wetted down prior to ultimate land fill burial.

The controlled burning dump has the advantage of conserving land burial area.

Sanitary Fill - The sanitary fill is the most commonly employed satisfactory method of refuse disposal when considered from an economic, esthetic, or sanitary point of view. It can be operated as a fill and cover for ravines, swamps, tide-lands, or gulleys, as well as for cut and cover on level land sites. One of the attractive advantages of sanitary fill is that it is possible to reclaim waste lands for specialized use and to convert them economically to a positive asset. The conversion of refuse fills into parks and airport sites has been a popular feature in many American cities. The gradual settlement of the filled land results in foundation difficulties demanding careful foundation engineering for heavy manufacturing and other building structures; this tends to limit the type of construction satisfactory for reclaimed land. Ashes from incinerators must also be disposed of to the land. Incineration is often considered a means of conserving the available land area by minimizing the volume of waste introduced into the receiving area. In part, burning can be through of as a treatment method rather than a final disposal method. Where available low cost land is situated adjacent to metropolitan areas, the sanitary land fill is accepted as an economic and satisfactory means of refuse disposal.

Water Disposal

The dumping of refuse into water bodies has in the past been a common practice among cities bordering on large bodies of water. New York, Oakland, and San Francisco for many years disposed of their refuse into the ocean.

Barges were employed to carry the refuse far out into the sea before the wastes were dumped. However, in almost all instances, currents carried the floatable refuse back to shore, causing nuisances. Furthermore, the cost of transferring to the barges and transporting the refuse far from shore was considerable. The law courts and economics have ruled that water dumping is generally an unacceptable disposal system.

Garbage Grinding

Garbage grinding either at individual homes or in municipal grinding stations is becoming commonplace. The ground garbage is handled as sewage in the water-carriage system and because of the small particle size is collected and disposed of by conventional sewage treatment methods. The feasibility of economical water-carriage of the other refuse components by grinding and discharge to the sewers remains an interesting item for future investigations.

Incineration

Incineration can be described succinctly as: disposal of the gaseous products and concomitant particulate matter to the atmosphere, and disposal of inert and unburned wastes to the land. Soluble minerals are dissolved by quenching water passing over ashes or contact with the ground water. The production of heat energy sustains and is a by-product of combustion.

Historical Development of Incineration

The British first developed the high temperature, municipal incinerator and their experience is worthy of careful review. In 1874, at Nottingham, England, Mr. Alfred Fryer built the first plant designed specifically for disposing of municipal refuse. Mr. Fryer applied for patents on his incinerator, stating the operating principle involved as "charge or supplying the refuse to the cells at the back and drawing out the clinker - the residuum - at the front." By 1900, over 40 municipal incinerators called "destructors" had been built in Great Britain. In that era the economies of utilization of clinker for construction material, the use of the available heat energy for a source of power, the high BTU content of the refuse and the low cost of manual labor promoted the technical development of British incineration practice. At the turn of the century, incinerators were built with a secondary chamber wherein boiler tubes were installed for heat transfer. In 1885, Mr. Charles Jones of Ealing, England, obtained a patent for using secondary fires in the main flue prior to discharge of the gases thru the stack in order to eliminate smoke and odors. Subsequent experience demonstrated that the cost of operating the secondary fires were generally prohibitive and a simpler solution for stack effluent quality control was to maintain high combustion temperatures in the range of 1250° to 2200°F., thus enabling both odor and smoke control as well as more efficient heat transfer. By 1920, the British had operated more than 200 municipal plants; however, following World War I and II, the heat energy content of the refuse and the value of power produced had so delined so that today there are only two important power-generating incinerators operating in the British Isles, (Birmingham and Glasgow.) In fact, today, separation of the collected refuse is often necessary in order to remove excessive mineral inerts so that a sufficiently high heat energy can be obtained in the combustible refuse. Recently it was reported that Britain has 30 conventional type incinerator plants and 70

separation incinerators. Most of these plants are used to handle very small tonnages. The first separation incinerator was built in 1919 and with only 3 exceptions, every British incinerator constructed since that time has been designed as a separation type plant.(1) Present day British refuse disposal is largely achieved by "controlled tipping" (landfill).

The first Continental plant was constructed at Hamburg, Germany in 1896. It was an improved English type "Destructor." Incineration has been little used in Europe and other parts of the world. There have been more municipal incinerators built in the United States than in any other country.

U.S. Incineration

Historically, in the United States, plentiful low-cost land has been readily available for dumping of refuse because of the dispersed nature of the populace. Increased urban growth and the development of large municipalities encouraged more complex practices, exemplified by New York City's early barging and dumping of refuse into the Atlantic Ocean.

The first American Incinerators were used for garbage disposal since this component of refuse provided the major source of disagreeable sanitary nuisances, namely vermin and odor. The first garbage "crematories" were low temperature burners that often produce both odors and fly-ash. They were not economical and usually required auxiliary fuel. The first "crematory" was built in 1885 for the U.S. Army at Governor's Island, New York. During the same year, the Rider Company built a municipal garbage "crematory" at Allegheny, Pennsylvania. In the following years, Des Moines, Iowa; Elwood, Indiana; and Minneapolis, Minnesota; each constructed plants of varying design, demonstrating such different features as water-jacketed, steel-lined, burning chambers and hanging grates. When these plants did not maintain high combustion gas temperatures, the operating problems were similar to those of the early garbage "crematories."

By 1906, a high temperature, British-type incinerator, employing forced draft, was built as Westmont, a suburb of Montreal, Canada. Variations of the relatively efficient British-made "destructors" found application in New York, Seattle, Milwaukee, Atlanta, San Francisco, and many other American Cities. Although numerous types of mechanical refuse charging devices were developed in England, Europe and the United States, manual charging and stocking prevailed through the 1920's. The modern U.S. trend is universally toward mechanized charging, stoking and more efficient controls. In the United States the utilization of incineration by-products, namely waste heat and ashes, has never developed as a basic operational factor.

U.S. Incineration Survey

The authors have undertaken a survey to determine the extent of U.S. municipal incineration experience. It is estimated that some 250 U.S. cities have built, in the past, a municipal incinerator. Questionnaires were sent to 226 of these municipalities and of this number, 122 replied to the survey form. 82 of these cities that answered still use incineration while 40, or approximately 1/3 of the cities answering, had abandoned their plants. Possibly many of the small communities that were questioned did not reply because they had abandoned their plants. Of the 106 cities described in the 1950 United States census as containing a population of 100,000 or greater, 69 cities are listed as having employed municipal incineration some time in their history. 53 of

these cities replied to the survey questionnaire indicating that 33 still utilized incineration (9 conserving the waste heat) while the other 20 cities had abandoned their plants for landfill. There are 17,452 incorporated small U.S. cities, with populations of 99,999 or less. Of the 122 communities that replied to the questionnaire, 82 still used their plants and 40 had abandoned them. Evidently, a much lower percentage (1.3%) of the smaller cities have municipal incinerators than in the case of the larger communities (65%). (see figure 4)

Location of Incinerators

Generally accepted criteria for locating an incinerator have been (1) to build on readily available or municipally owned land, and (2) minimize haul for maximum economy and convenience. However, there are other important factors that should be considered for optimum location of a plant. In the largest metropolitan centers, it is generally not advantageous to build one big incinerator to handle all the refuse but, rather, to construct smaller units strategically placed. It is desirable to locate the plant in an industrial area, where odors from the collecting vehicles and fly ash from the plant impose minimum nuisance. Furthermore, refuse salvage and waste heat utilization can best be undertaken close to the ultimate market.

Another important factor in building an incinerator is to locate it, so that if possible, there is available two-level topography. Ideally, the collected refuse should be directly dumped in at the top level, burned within the combustion chambers at an intermediate level while the ashes are removed at the bottom elevation and finally disposed of in a nearby pit. Hillsides are adaptable for such two-level construction. Thus minimum mechnical refuse handling equipment and ramp building or tunnel excavation is required.

Ash residue disposal involves a significant portion of the refuse collected - ranging between 5 to 45% by volume. A plant location with nearby ash disposal is economically desirable.

The topography of an incinerator site not only influences the construction costs but may also affect the wind pattern; down-drafts in hilly areas interfere with the disposal of the stack gases. The plant stack should be 100-200 feet above the local ground level so as to (1) obtain good draft and avoid the possibility of flashbacks due to pressure changes in the burning chambers, (2) assure proper stack gas dilution, (3) reduce flyash nuisance and (4) utilize the psychologically beneficial effect on the public of an elevated discharge.

The desirability of building incinerators in areas where atmospheric pollution is already a problem is open to question. Atmospheric inversions may permit smoke concentrations that, together with other industrial combustion products, may blanket an area with objectionable air pollutants. The lack of sufficient diluting air for stack effluents may result in the incinerators located in such regions being contributory to a general "smog problem." Significantly, where air pollution is a community problem, there are governmental air pollution control enforcement agencies. These agencies establish incinerator stack-gas quality regulations necessitating expensive air pollution control equipment designed to limit the amounts of atmospheric pollutants discharged to the air.

Incinerator ash disposal may also be required to meet local water pollution control laws. Zoning ordinances may restrict the location of a plant. While it is true that it is possible to place incinerators in expensive, totally-enclosed

structures so that there is a minimum of nuisance, movements of heavy collection vehicles on the streets and some noises and odors cannot be avoided.

By-Product Heat

Most American refuse contains an average calorific content of between 3500 and 4500 BTU per pound. This amount of heat energy will vaporize approximately 3 to 4 pounds of water into steam. In practice, incinerators have been able to produce between 1-1/2 and 2-1/2 pounds of steam per pound of refuse burned. In addition to supplying utilizable heat, refuse must first produce the heat energy required for (1) maintaining combustion gases and incinerator refractories at high temperatures; (2) vaporization of the moisture present in the refuse; (3) raising the temperature of freshly introduced refuse to the kindling point; and (4) preheating draft air.

By Product Ash

Ashes and clinker have been used to a limited extent in the United States for road building and light-weight concrete manufacture. Complete, but economical, high-temperature burning is required to obtain an organic-free ash suitable for such utilization. Ashes have also been used for fertilizer and flyash from the secondary chamber may be employed as an inert base in the preparation of insecticides and other powder-base industrial products. The salvage of tin cans, either before or after partial burning, represents another waste product that is sometimes profitable in conjunction with normal plant operation. Atlanta, Georgia and Miami, Florida have successfully carried out ash and tin can by-product utilization. (Table 2)

TABLE 2

Examples of Salvage as Practiced in Some American Cities

City	Type of Salvage Operation
Atlanta, Georgia	Burned tin cans from incinerator salvaged for use in local foundaries.
Beverly Hills, California	Cardboard cartons and paper salvaged for paperboard processing. Cans and bottles separated and salvaged.
Los Angeles, California (over thirty cities in Los Angeles Metropolitan Area practice same salvage)	Tin cans processed by controlled burning for use in copper mining. Bottles and glass salvaged for direct reuse or melted and re-molded.
Miami, Florida	Burned tin cans from incinerator salvaged for foundry use.

Costs

Typical costs of municipal incinerator construction, maintenance and operation are graphically summarized in figures 5 and 6 respectively. The current trend has been towards construction costs of greater than $2,000 to $3,000 per ton of rated 24-hour burning capacity. Incineration of refuse is a

relatively expensive process and even with economical installation, the costs are generally greater than $2.00 a ton of refuse burned. Cost as high as $4.00 or $5.00 per ton for burning refuse has been reported by city engineers maintaining complete and accurate records. Air pollution control equipment may increase future incineration construction and operation costs.

Incinerator Components of Contemporary Plants

Weighing - In large-capacity installations, it is desirable to use recording platform scales which operate semi-automatically and are able to weigh and record 60 to 70 refuse trucks per hour with minimum standing time. The plant should be laid out so that straight-line flow is employed; after the refuse is weighed, the truck should be driven forward to the dumping floor avoiding, if possible, any necessity to back out, so that it may return to the collection route rapidly. The weighmaster should keep careful weight records, classifying the loads whenever possible.

After weighing, the weighmaster should direct the truck driver to the point where the refuse should be dumped so that (1) heat energy of refuse charged to the incinerator furnace will be maintained as constant as possible, and (2) the materials handling is reduced.

Unloading - Many incinerators operate 4 to 8 hours a day with refuse unloading in proximity or directly into the primary or furnace chamber. In such installations, no provision is made for storage of the unloaded refuse. This is often unsatisfactory, since the plant cannot be maintained in a clean sanitary condition when refuse is piled on the dumping floor. On the other hand, where storage pits are employed, considerable expense is introduced for the use of overhead mono-rail or bridge cranes to charge the refuse into the furnace. One disadvantage of directly charging the refuse from the collection truck into the primary chamber is that it is impossible to maintain continuous, small-volume charging. With the batch process the furnace is either underloaded or overloaded. At Pasadena, California, a small 80 cubic yard storage bin is emptied by a movable, metal endless belt, approximately 15 feet wide, to efficiently and almost continuously feed refuse into the burning chamber.

Charging Inlet - The charging gates in most modern plants are operated hydraulicly, pneumatically, or electrically. The charging inlet may vary in size from less than 4' to 6' to as much as 5' x 15'. Observations on many municipal incinerators indicate that the amount of air introduced into the furnace thru the charging gate when charging does not seriously deter the burning process because (1) the fresh refuse requires additional oxygen and (2) the differential gas pressure at the inlet is slight. Large inlets, with wing wall entrances, are desirable so that large tree stumps, boxes and other refuse which would otherwise require considerable labor to reduce their size may be fed into the incinerator. (see figure 7 for schematic drawing of incinerator)

Primary Chambers - The primary burning chamber confines the combustion and enables the refuse to dry out and burn. An efficient plant will provide a maximum of pre-drying with the aid of the waste heat otherwise discharged to the atmosphere. For maximum performance the furnace will continuously feed refuse to the burning hearth while the residue and ashes are removed.

A common type of mechanically-stoked furnace utilizes a rotating rabble. The rotary kiln furnace is another method of reducing labor expense for stoking and ash disposal; unfortunately, it is an expensive structure to build. A

further type of modern primary chamber is the suspension grate, which provides two burning surfaces in the primary chamber. The suspended grate acts as a drying hearth where the fresh refuse is desiccated before being dropped to the burning grate and stoked for ash disposal. Traveling grates and movable pallets are types of continuous metallic belts adapted from coal burning practice.

Forced draft is often provided by blowing in (1) air at atmospheric temperatures, (2) steam heated air, (3) recuperator heated air, or (4) partially recirculated combustion gases. The partial recirculation of heated gases has proved to be an economical type of installation. Chamber and gas temperatures can be controlled with forced draft to impliment high burning rates. When furnace temperatures are too high, additional cold air may be introduced to reduce the burning environment to the desired temperature; on the other hand, when primary burning chamber temperatures are too low, auxiliary fuel, recirculated gases, and reduced forced draft may be resorted to.

Ash storage may employ mechanical devices to collect the primary chamber residue and discharge it by gravity into some disposal system. Conventional incinerator operation produces between 5 to 45% ash content by volume. Incinerator residue removal can be mechanically achieved thru hydraulically or manually operated dumping grates, shaker grates, rotary kilns, and traveling pallets. Comparatively large openings (4' x 8') for easy removal of incinerator residue are desirable. Ashes should be throughly quenched in a water bath or spray to eliminate further burning at the dump site. Conveyor belts for ash removal are expensive to install, are subject to severe corrosion and abrasion, and require constant repair and maintenance.

Secondary Chambers - It has been previously noted that secondary chambers were first utilized by the British for installing waste-heat boilers. When heat exchangers are introduced in the primary chambers they tend to cool the combustion environment so that it is difficult to maintain optimum burning. Other reasons for the secondary chamber are to promote the complete combustion of burning gases and to settle flyash. A crematory door for small animals and a flyash cleanout are usually provided in the secondary chamber. In incinerators operating at less than rated capacity it has been noted that the temperatures in the secondary chambers are usually from 100 to 300 degrees F. lower than the temperatures in the primary or burning chamber; however, in incinerators operating at capacity or at greater than rated capacity it has been noted that the gas temperatures in the secondary chamber are as much as 400 degrees F. higher than in the primary chamber.

Further Components

Blowers, fans, flues, particulate-matter control devices and the stack are additional plant appurtenances. Since the primary and secondary chambers require a negative air pressure head of 1 to 4 inches of water for proper operation it is necessary that the flues and stack be designed to permit correct gas flow. The negative air pressure head enables the introduction of overfire and underfire air into the burning chambers without flashback thru the charging doors. Stacks are often used to produce the negative pressure head, although induced draft fans are becoming increasingly common.

Particulate Matter and Stack Gases

Particulate matter may be removed from the combustion gases thru the medium of (1) baffle chambers, (2) gas expansion and sedimentation chambers, (3) complicated duct work, (4) cyclone precipitators, (5) dynamic centrifugal precipitators, (6) sonic glomerators, in conjunction with a cyclonic precipitators, (7) wet chamber employing a water bath or water spray, (8) bag filters made of steel or glass mesh, and (9) electrostatic precipitators. However, control of particulate matter is costly, and the finer particles are not completely removed by even the best processes. Tests of stack gases indicated that flyash may represent as much as 1% by dry weight of the total ash produced. Large burning flyash particles may cause fires in the surrounding area, besides settling out as an objectionable coating that litters the neighborhood and produces complaints from the citizenry.

Flues may transmit the burned gases to the stack with velocities of from 5 to 25 feet per second. In these flues there should be instruments, including thermocouples for temperature recorders, carbon dioxide recorders, smoke recorders, etc. Each component of the plant should have adequate automatic recording instruments so that maximum supervision of plant performance can be maintained. Carbon dioxide, it should be noted, is a good criterion of the air to fuel ratio and, in conjunction with the burning temperature, can be employed as a general criteria for plant combustion efficiency. With high concentrations of CO_2, low air to fuel ratios prevail and high temperatures may exist, perhaps indicating the need for additional air in the primary chambers. When the inverse is true, excess air should be reduced.

An incinerator discharges small quantities of gases such as aldehydes, oxides of nitrogen, and sulfur dioxide. The presence of partially oxidized gases is a result of incomplete combustion. It is not reasonable to expect that complete oxidation will occur at all times in the burning process since chemical-thermodynamic reactions cannot practically be expected to go to completion during the time the gases are retained in the incinerator. The concentration of particulate matter and gases present in stack effluents can be reduced by blowing in diluting air at the base of the stack; however, this does not effect a reduction in the original weight of flyash and combustion gases discharged into the air, but merely represents dilution. A combination of carefully designed expansion chamber, baffle walls, checker flues, and particulate control systems should effectively maintain flyash and stack gas quality within workable limits.

Refractories

Refractories are fire brick made from heat resistant clay and minerals. Refractories capable of withstanding extremely high temperatures and resisting thermal expansion and contractions contain large percentage of alumina. The alumina-silica refractory may contain between 15% and 90% alumina; the higher the content of alumina, generally the better the refractory quality and the greater the resistance of the refractory to thermal shock. Silica has the undesirable characteristic of a high coefficient of expansion between the temperatures of 200 and 300^{O}F. As a result of this expansion, considerable spalling will be present when high silica refractories are used in the incinerator. Refractories can be purchased and installed either as bricks or as plastic. The bricks require masonry construction while the plastics are tamped in place with formwork (see figure 8). Bricks are burned in the manufacturer's

kiln, but plastic refractory material, consisting of essentially the same chemical composition as the brick, receive their burning in place in the incinerator. The plastic refractory should be burned-in carefully to develop good ceramic bond characteristics. Either type construction was observed to be satisfactory. Plastic material can be very readily used for repair of burned out refractories. Continuous 24-hour high-temperature burning is more desirable for refractories than intermittant cooling and heating caused by 8-hour a day operation.

Laboratory Control

A simple laboratory for control of the refuse burning is a necessary part of any incinerator. Incineration should be carried out as a rigorous engineering activity rather than a confused art. High-caliber engineering personnel, capable of operating a control laboratory, should be a mandatory feature of future incinerators. Certainly an investment of from a half a million to five million dollars for an incineration plant justifies the use of able technical personnel and advanced scientific controls.

Rating Incinerator Capacities

Recent field tests on two mechanically-stoked municipal incinerators in Southern California demonstrate some interesting possibilities for re-evaluating incinerator performance. Unfavorable economic comparison with cheaper landfills requires a revision in the approach to incineration, to establish more realistic design criteria.

The primary reason for the incineration of combustible rubbish is the desire to reduce to a minimum the volume of material which must ultimately be buried. Where garbage is to be disposed, incineration is a method of eliminating the putrescible nature of the refuse. Incineration should be recognized as but one of several alternative steps in the treatment of refuse prior to ultimate disposal; it serves principally as a means of prolonging the use of landfills and permits a wider selection of land areas for final residue burial.

Ash Quality

Obviously, to produce an ash suitable for salvage requires that burning be carried out to virtual completeness. This involves very high temperatures and prolonged periods of flame contact, dictating a need for relatively large, expensive structures. As most incinerator ashes are buried and not used, it is in the interest of economy to determine the optimum, not maximum, volume reduction to be achieved by burning.

Volume Reduction

The reduction in volume accomplished during the initial brief exposure to radiant heat and burning flame represents a significant volume reduction. During the first 10 minutes of burning (excluding installations burning wet garbage and sewage sludge) a far greater volume reduction occurs than during the following 10-minute interval, with progressively less volume reduction each subsequent 10-minute increment. This is a demonstration of the "law of diminishing returns."

Consider the burning activity in a mechanically-stoked, primary burning chamber; almost all of the high surface-area, low-density material such as loose paper, leaves, and readily volatile components in the refuse may be oxidized by flash burning. To burn thick tree branches and similiar heavily insulated objects requires considerably longer contact time. To remove the final 5% of the unoxidized components may require a burning process fully as extensive as that required for oxidation of the first 95%. Hence, an incinerator which is forced to burn refuse to the point where less than 1% unoxidized material remains in the ash residue (a fairly common acceptance test requirement) is doing relatively little volume reduction in the final burning stages.

Appearance of High-rate Burned Residue

Partially burned refuse requires more care in handling and disposal than does well-oxidized incinerator residue. Not only are the partially burned paper, tree limbs, etc. unsightly and odorous, but because of the organic content they must be treated as though crude rubbish were being disposed of at a landfill. However, if the residue is buried with the proper sanitary landfilling techniques, the ultimate result will be economical, sanitary and esthetically acceptable. The less dense components having been eliminated, the remaining partially-burned residue can be compacted so as to minimize subsequent settlement.

Ash storage and ash removal appurtenances in an incinerator designed to achieve optimum volume reduction must be designed to handle the greatest volume of ashes produced and to discharge the larger objects in the residue so as to avoid clogging. Partially burned refuse must be thoroughly quenched to prevent the continued burning of the organic matter in transport and at the landfill.

Temperature of Combustion

The factor which governs the chamber temperature is the rate of heat release. When an incinerator is operated at less than design capacity there may not be sufficient heat released to raise refractory wall and combustion gas temperatures up to the range of 1200 to 2000^{O}F; however, this does not mean that combustion is incomplete, provided that released gases do not cool so quickly as to cease burning. Conversely, it is possible to "overload" an incinerator far beyond its "design" capacity without refractory temperatures rising beyond a reasonable limit. This may be accomplished by introducing air and rubbish so rapidly that large quantities of heat energy are used in raising the temperature of the refuse to the kindling point, while the gases are vented thru the incinerator stack.

Design Consideration

To achieve the optimum rate of volume reduction the raw refuse should be introduced continuously and exposed to flames or chamber temperatures sufficient to dry and kindle it. Following initial burning, the refuse must be given sufficient grate area and adequate agitation with air so as to burn in turbulant suspension and avoid being smothered with new refuse, otherwise the combustion process may be slowed down instead of accelerated. The partially-burned, high-density residue should then be quickly removed from the primary burning chamber to prevent the clogging of grates, as this tends to reduce the

under-grate air needed to sustain the rapid burning of loose and volatile combustibles in the freshly introduced refuse. Over-all incinerator burning temperatures in the range of 2000°F, although resulting in slag formation, obviously promote high combustion rates and should be used when feasible.

Conveyor charging can approximate continuous feeding, while rotary kilns or traveling grates provide maximum control over the length of the burning period.

Principles of Combustion

To understand the fundamental operation of a refuse incinerator it is desirable to review some of the basic requirements for self-sustained combustion of refuse in an incinerator.

Combustible Refuse

Combustible refuse consists of such common organic compounds as grass, tree trimmings, paper, cartons, carpets, rags, rubber, garbage, petroleum products, ash from hard fuels, and similar wastes. Chemically, the wood and paper refuse is largely composed of cellulose and lignin. The heat energy value of the combustible materials can be determined accurately in a bomb calorimeter. When the particular heat value of the combustibles are known, an accurate prediction of the available heat energy can be made on a basis of percentage moisture and percentage of inert material present (see figure 9). Representative calorimeter measurements of BTU values of refuse samples are listed in figure 9.

Burning Process

From physical and chemical analyses of the material to be burned, one can calculate the weight and volume of ashes and gases which will result from combustion within the incinerator. Raw material should be introduced into the primary burning chamber with a minimum of handling. Cutting of the refuse increases the operating costs and should be avoided. Refuse introduced into the primary chamber is exposed to hot burning gases and radiant heat emanating both from the refuse fire and the red hot refractory walls. The refuse is dried and the excess moisture is evaporated; the steam is drawn off subsequently with the combustion gases. The flame temperature of the burning refuse may be as high as 3000°F.

The greater the ratio of surface area exposed to the drying environment, the more rapid will be the drying. The radiant heat from the refractories and the flame temperature of the burning refuse supplies the heat energy to the gases in the incinerator. The speed of drying is increased when makeup air is preheated and rapidly moving, thereby quickly evaporating moisture. This provides new burning surfaces that burst into flame at the fire ignition point temperature of the refuse material. (See Table 3 for fire ignition point of various materials.) Agitation of the raw refuse and exposure of the refuse surfaces to the hot gases promote quick drying and rapid burning.

TABLE 3

Fire Ignition Point Temperatures for Various Materials

Material	Temperature °F
Asphalt	535
Coal Gas	1,100
Carbon	1,300
Wood	350
Paper	350

Mass Balances and Heat Balances

The law of conservation of matter indicates that over a certain time period, the total products of combustion discharged from an incinerator must equal the total amount of material introduced into it. The available sources of mass and energy and the dispersal of mass and energy are described in the following mass and heat balances.

Thermodynamic Calculations

Preliminary Calculations for Mass and Heat Balances

Assume that calorimeter tests show that a certain cellulose-type refuse will liberate approximately 9,600 Btu per lb. on a dry, inert-free basis. Secondly, assume analysis indicates 40% moisture and 10% ash in the refuse:

1. The heat energy liberated by 1 lb. of raw refuse = 50% x 9,600 or = 4,800 Btu per lb. wet basis. This energy represents the heat supplied to the incinerator per lb. of introduced material on a wet basis (including moisture and inert matter).

The heat used in burning process is expended thru:

a. The stack gases.
b. The refractories by conduction.
c. The ashes.

The moisture content of the refuse was experimentally determined to be 40% moisture. Therefore:

1 lb. raw refuse x 40% = .4 lb. water in the refuse.

Assume a relative humidity of 50% at 69°F in the air. There are approximately 40 grains of water per lb. of this air. Assume that the oxygen in the air is chemically combined with the refuse and that this refuse is $C_6H_{10}O_5$ (cellulose).

2. $$C_6H_{10}O_5 + 6O_2 = 6CO_2 + 5H_2O + 4{,}800 \text{ Btu energy}$$ (for 1/2 lb. fuel)

Molecular weight (162) + (192) = (264) + (90)

0.50 lb. + 0.59 lb. = .82 lb. + 0.28 lb. water

From this reaction it is determined that 0.59 lb. of oxygen or 2.57 lb. of air are needed to oxidize 0.5 lb. of cellulose.

Assuming 200% excess air is used, then 7.71 lb. of air are blown into the primary chamber.

3. Moisture in air = $\frac{40 \text{ gr.}}{\text{lb.}} \times \frac{\text{lb.}}{7{,}000 \text{ gr.}} \times 7.71 \text{ lb. air} = 0.04 \text{ lb. water}$

4. Total water discharged in stack gases = 0.40 lb. water in the refuse
+ 0.04 lb. water in air supply
+ 0.28 lb. water formed in oxidation reaction
Total stack moisture = 0.72 lb. water per lb. of refuse

Assume that gas temperatures in the stack are maintained at 600°F by a heat exchanger which absorbs heat energy not used otherwise.

5. Heat required to bring water to boiling point = 0.72 lb. x (212°F-60°F) x 1.0 = 110 Btu (use average specific heat = 1.0)

6. Heat to evaporate water to steam = 0.72 lb. x 975 Btu = 700 Btu

7. Heat required to raise steam to 600°F = 0.72 lb. (600°F-212°F) 0.5 = 140 Btu (assume specific heat of steam = 0.5)

8. Total heat needed to raise water to 600°F = 110 Btu + 700 Btu + 140 Btu = 950 Btu

Heat needed to raise stack gases to 600°F. (assume specific heat of air, including CO_2 = 0.25)

9. With 200% excess air: (3 x 2.57 lbs.)
Total weight gases = 7.71 lb. air - 0.59 lb. O_2 + 0.82 lb. CO_2 = 7.94 lb.
Btu gases = 7.94 lb. air x (600°F-60°F) x 0.25 = 1,072 Btu

10. With 50% excess air: (1.5 x 2.57 lbs.)
Total weight gases = 3.85 lb. air - 0.59 lb. O_2 + 0.82 lb. CO_2 = 4.90 lbs.
Btu gases = 4.90 lb. (600°F) x 0.25 = 660 Btu

11. Heat loss due to incomplete combustion: (Assume that 2% of the original material by dry weight remains unburned.)
Btu incomplete combustion = 0.02 x (0.5 lb. x 9,600 Btu) = 96 Btu

12. Heat loss of hot residue: (Assume average temperature 500°F in the ash and clinker.) Specific heat residue = 0.20

The residue represents 12% of the original weight of the material.
Btu residue loss = .12 x 1 lb. x (500°F-60°F) 0.2 = 13 Btu

13. Other heat losses: (Assume 5% is lost to refractories, open doors, etc. Estimated from tests on incinerators.)
Btu = 4,800 Btu from lb. raw refuse x .05 = 240 Btu

Heat Energy Balance

14. Summary of Heat Energy

Uses for 200% Excess Air	Heat Energy Available (per lb.)
950 Btu moisture (600°F)	9,600 Btu x 0.5 = 4,800 Btu
1,072 Btu gases (600°F)	
13 Btu hot residue	
96 Btu incomplete combustion	
240 Btu other losses	
2,371 Btu Total Energy Used	

15. Available waste heat energy = 4,800 Btu (total energy available)
- 2,371 Btu (total energy used)
= 2,429 Btu per lb. of waste material

Thus, one can calculate that 2,429 Btu are available for outside heat utilization per lb. of refuse burned. It is possible to determine how much steam can be produced for generating power or other uses. Approximately 1,200 Btu are needed to convert 1 lb. of water to steam.

16. Water which could be converted to steam (assuming 100% efficiency) =

$$\frac{\text{Available waste heat Btu}}{1{,}200 \text{ Btu}} = \frac{2{,}416}{1{,}200} = 2.01 \text{ lbs.}$$

Effect of Excess Air in Cooling the Primary Chamber

The Btu needed to raise the air in the primary chamber to 1,300°F can be calculated as follows:

17. Air weight with 200% excess air = 3 x 2.57 = 7.71 lb. of introduced air
    Btu to heat air (assume) = 7.71 (1300°F-60°F) (0.25) =
    specific heat = 0.25) 2,390 Btu (200% excess Air)

18. Air weight with 50% excess air = 2.57 x 1.5 = 3.85 lb. of introduced air
    Req. Btu to heat air = 3.85 (1300°F-60°F) (0.25) =
    3.85 (1240°F) (0.25)
    = 1190 Btu (50% excess air)

Primary Chamber Temperatures

To approximate the gas temperatures in the primary chamber the following procedure may be followed:

19. With 200% excess air = 7.12 lb. x 0.25 specific heat = 1.78
    CO_2 = 0.82 lb. x 0.22 = .18
    H_2O (steam) = 0.72 lb. x 0.50 = .36
    2.32
    weighted specific heat. (heat energy required to raise products of combustion from 1 lb. of refuse 1°F.)

20. The average temperature increased with 200% excess air = $\frac{\text{Available waste heat energy}}{\text{weighted specific heat}}$ =
    $\frac{2429 \text{ Btu}}{2.32} = 1{,}050°F$
    Approximate primary chamber temperature = the average temperature increase + the assumed temperature for the heat energy balance
    = 1,050°F + 600°F = 1,650°F

21. With 50% excess air = 3.03 lb. x 0.25 specific heat = .76
    CO_2 = 0.82 lb. x 0.22 = .18
    H_2O = 0.72 lb. x 0.50 = .36
    Total weighted specific heat = 1.30
    The average temperature increase with 50% excess air = $\frac{\text{Available waste heat energy}}{\text{weighted specific heat}}$ =
    $\frac{2841 \text{ Btu}}{1.30} = 2{,}180°F$

Approximate primary chamber temperature = the average temperature increase + the assumed temperature for the heat energy balance
= $2,180^{o}F + 600^{o}F = 2,780^{o}F$

Once the approximate primary chamber temperature is known, it is possible to recalculate the energy balance for this condition. The mathematical summary of the heat energy used and the heat energy available should balance and be equal when the correct primary chamber temperature has been used.

Heat Energy Required to Bring Refractories up to Operating Temperature

Thermodynamic calculations can be made to determine the amount of heat energy required to raise the temperatures in the primary furnace to $1,300^{o}F$ operating temperature, by means of the following formula:

22. Heat Energy = Specific heat x mean temperature increase degree Frahrenheit x the weight of the furnace refractories

Assuming specific heat of 0.28

Mean temperature increase of $1,300^{o}F-60^{o}F$ = $1,240^{o}F$
Average temperature increase = $1,240^{o}F/2=620^{o}F$
Refractory wall thickness = 9 inches

Volume of refractories in a primary chamber (1,000' surface area and 9" thickness) = 750 cu ft of refractory material and with a weight of 140 lb. per cu. ft. of refractory

Heat energy = 0.28 ($620^{o}F$) 750 cu. ft. x 140 lb.
= 18,000,000 Btu (heat energy from approx. 1.8 tons of raw refuse material.)

Heat Energy Transferred by Refractories

It is possible to calculate the heat losses as a result of the transfer of heat thru the refractory. For example, the heat losses as a result of the transfer in the primary chamber can be calculated as follows:

K = Conductivity constant $1,300^{o}F$ = 10
Temperature at the hot face = $1,300^{o}F$
Temperature at the cold face = $150^{o}F$
Thickness = 9 in.
Surface area = 1,000 sq. ft.

23. Btu heat transfer per hour = Constant x (temperature (^{o}F) of hot face - temperature of cold face) x surface area (sq. ft.) ÷ thickness in inches of wall

$$= \frac{10\ (1,300^{o}F-150^{o}F)\ 1,000\ \text{sq. ft.}}{9\ \text{in.}}$$

$$= \frac{10\ (1,150^{o}F)\ 1,000\ \text{sq. ft.}}{9\ \text{in.}}$$

= 1,280,000 Btu (heat energy from approximately 250 lb. of raw refuse material)

Cooling Effect of Raw Refuse Introduced into the Primary Chamber

The introduction of raw refuse into an incinerator fire causes an initial cooling effect. The new fuel, before it can give out any heat by its own combustion, must first be warmed to its ignition temperature. This will generally vary between 500°F and 1,300°F, depending on the characteristics of the refuse. (Assume 60°F room temperature and 1,300°F furnace temperature. The specific heat of the refuse can be considered to be about 0.25. The percent moisture of the refuse is 40.)

Hence if a 1 lb. charge is fired:

Assume specific heat of refuse = 0.25
Temperature of ignition = 1,300°F
40% water in refuse

24. Btu needed to heat refuse = 0.6 lb. (1,300°F-60°F) 0.25 specific heat
= .15 (1,240°F) = 186 Btu

Moisture in refuse	= 0.4 lb.
Moisture in air supply	= .04 lb.
Moisture in chemical reac.	= 0.28 lb.
Total moisture in refuse sample	= 0.72 lb.

25. Btu to bring water to boiling = 0.72 (212°F-60°F) (1) = 115 Btu

26. Btu to evaporate water = 0.72 lb. (975 Btu) = 700 Btu

27. Btu to raise steam to 1,300°F gas temperature = 0.72 (1,300°F-212°F) 0.5 = 0.36 (1,088°F) = 392 Btu

28. Total Btu to heat water = 115 + 700 + 392 = 1,207 Btu

29. Btu needed to raise 1 lb. raw refuse to 1300° combustion temperature = 1207 heat for H_2O + 186 heat for refuse = 1393 Btu

Mass Balance of Material Entering and Leaving Incinerator

It is possible to use the type of calculations just shown (Nos. 1-29) to design the various components of an incinerator. These calculations can be checked for accuracy by a cross calculation called the mass balance, i.e., the quantity of introduced materials should approximately equal the quantity of discharged materials.

Assume 200% excess air.

30. Introduced Material

Inert Material	= 0.10 lb.
Combustible Refuse	= 0.50 lb.
H_2O in refuse	= 0.44 lb.
Dry air	= 7.71 lb.
H_2O in air	= .01 lb.
	8.76

Discharged Material

Ashes (grate & fly)	= 0.10 lb. (assuming complete combustion)
CO_2	= 0.82 lb.
Total H_2O	= 0.72 lb.
Other stack gases	= 7.12 lb.
	8.76 lb.

SUMMARY

1. Refuse disposal should be sanitary, convenient, and economical.
2. Refuse disposal is influenced by the frequency and method of collection.
3. Transfer stations can be employed for reducing the costs of transporting refuse.
4. Salvage, hog feeding, composting, garbage reduction, landfill, water disposal, and garbage grinding are alternative refuse disposal systems.
5. The British were the first to construct high temperature "destructor" plants in the latter part of the 19th century. They developed the incinerator to produce by-products such as clinker for building materials and steam for heat and power. In recent years the British have found sanitary landfill more economical for most refuse disposal.
6. In the U.S. incinerators were originally used to burn garbage. As the nation's population increased, incinerators were employed by metropolitan cities to conserve the limited land disposal sites.
7. Approximately 250 U.S. cities have used incinerators, the other municipalties are largely dependent on sanitary landfill.
8. Incinerators should be located to satisfy the following factors:

   (a) maximum economy of collection haul, (b) operation in an industrial area to reduce nuisance and promote refuse salvage, (c) two-level topography for minimum construction costs, (d) reduction of atmospheric pollution and (e) convenient ash disposal.
9. American incinerators have made little use of by-products such as heat or clinker. Burned tin cans have been salvaged by some U.S. cities.
10. Incineration is a relatively costly refuse disposal process, involving from $2,000 to $5,000 per rated ton of 24 hour burning capacity for construction costs, and ranging from $2 to $5 per ton of refuse burned as actual operating cost.
11. U.S. incinerators are tending to become more mechanized as labor costs increase.
12. Incinerator components include (a) weighing station, (b) unloading facilities, (c) charging, (d) primary drying and burning chambers with mechanical stoker, ash disposal, and forced draft, (e) secondary chamber, (f) flues, stack and particulate matter control devices.
13. The percentage of CO_2 concentration in the stack gases can be used as a means of controlling the air to fuel ratio.
14. The particulate matter discharge from an incinerator stack can be controlled by settling, electrostatic precipitation, entrapment, filtering, and other such processes or devices.
15. Refractories are important elements in effective operation of an incinerator. Plastic refractory material can be used for repair of exposed surfaces.
16. Good laboratory and technical control should be employed to obtain optimum performance from expensive incineration plants.

17. High rate burning, using optimum volume reduction rather than complete oxidation, may be desirable to reduce incineration costs.

18. High rate burning does not completely burn large limbs and other well-insulated refuse but rather flash-burns low density material to minimize the volume of residue for land disposal. Special incineration design is required for successful high rate burning and should include the following: turbulent suspension of the introduced refuse, high temperature burning, continuous feed of refuse and continuous removal of residue, thorough quenching of residue, and final sanitary land burial of the odorous residue.

19. The burning process in an incinerator includes drying the refuse, heating to the fire ignition point, and then flame burning in the presence of oxygen supplied by air.

20. Examples of Thermodynamic calculations for mass balance and heat energy utilization are given.

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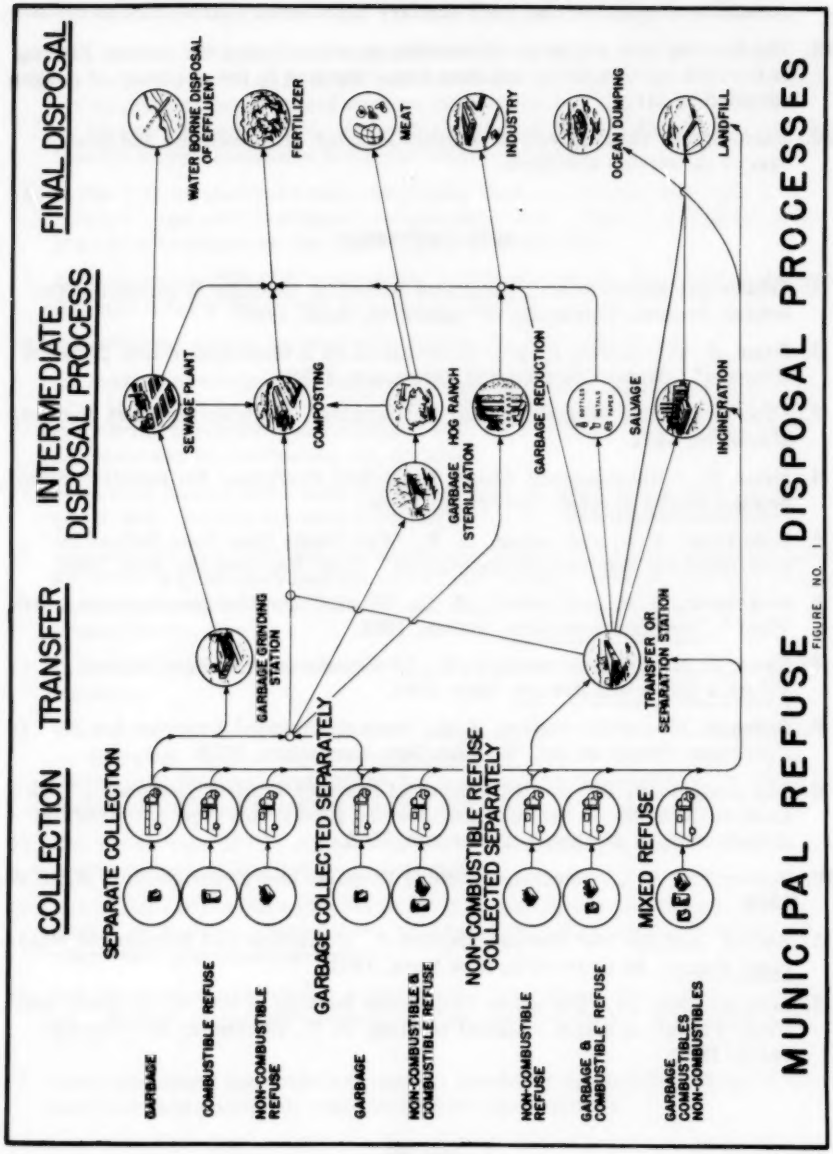
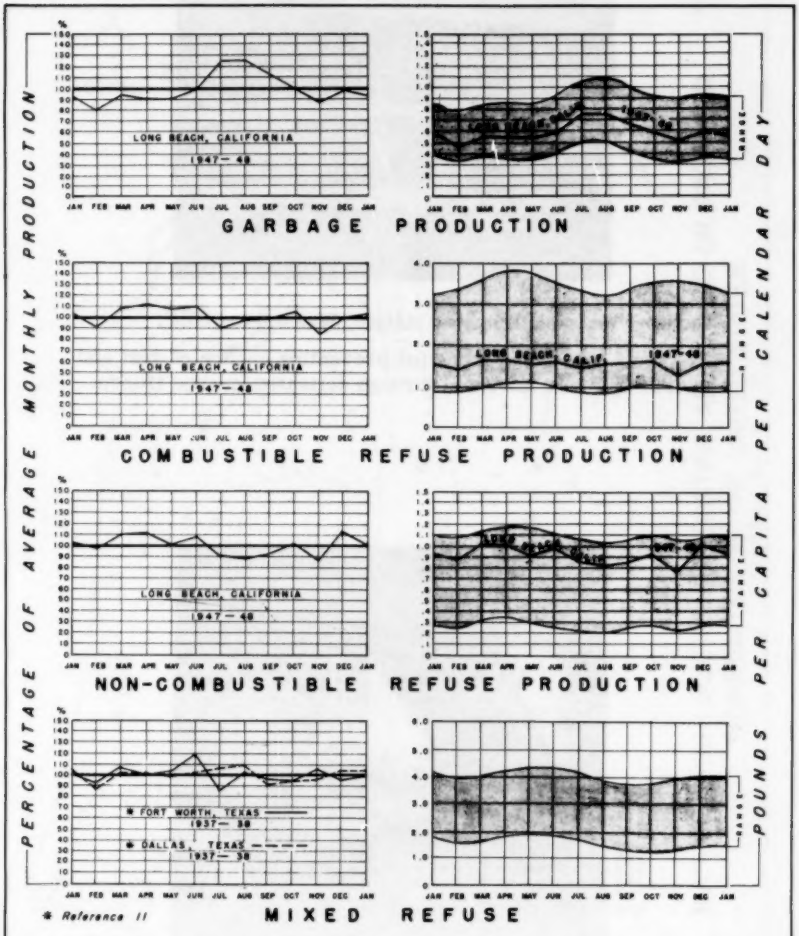


MUNICIPAL REFUSE DISPOSAL PROCESSES

FIGURE NO. 1



SEASONAL VARIATIONS IN REFUSE PRODUCTION

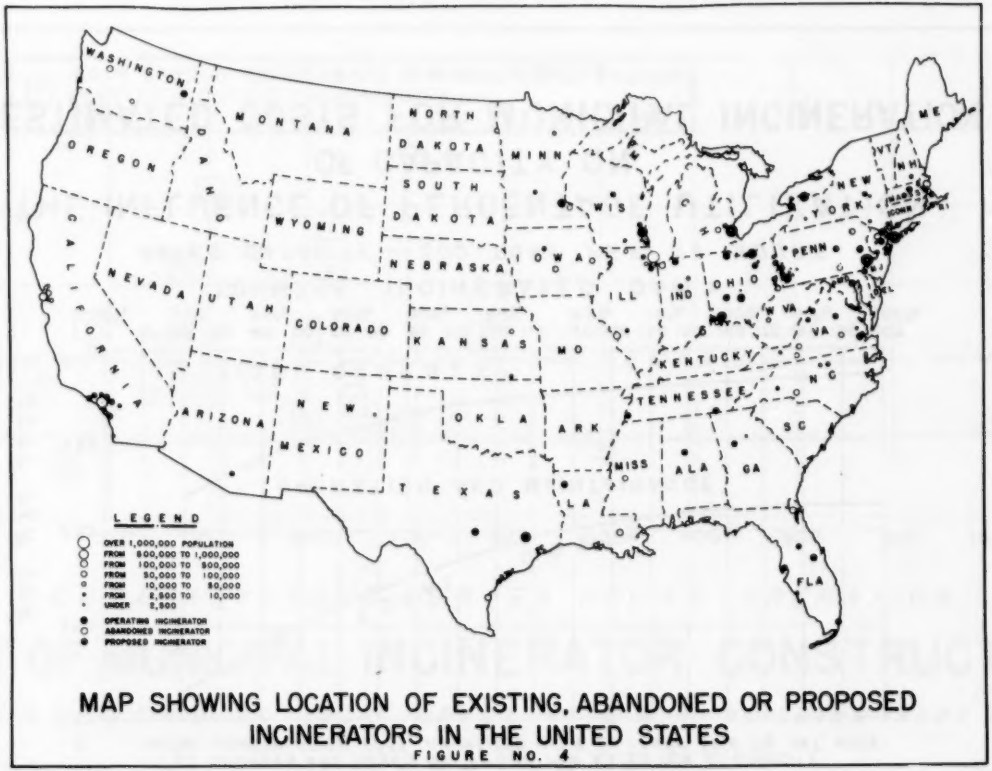
FIGURE NO. 2

Garbage and Ash Transfer Station, Washington, D.C.

Note roll-type steel doors for preventing escape of dust and odors. Interior is vented through activated-carbon filters.

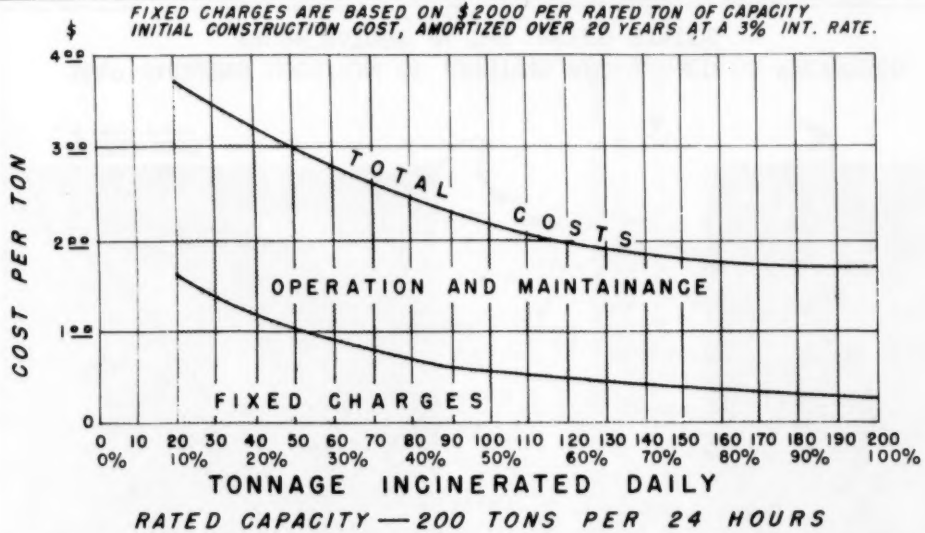
Garbage Truck transferring load to large-capacity trailer at Washington, D.C.

Figure 3



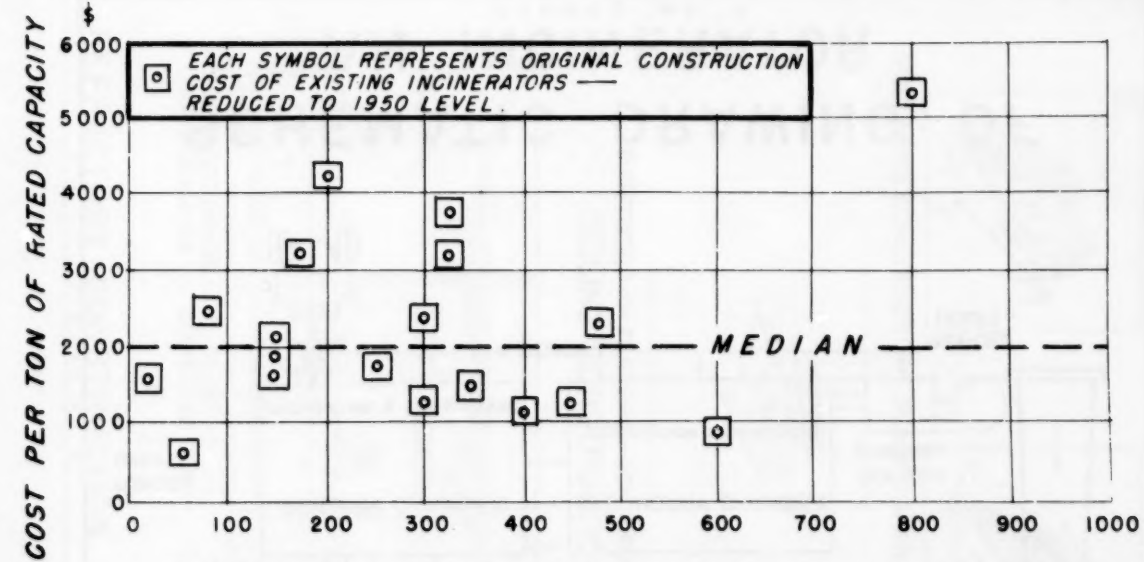
MAP SHOWING LOCATION OF EXISTING, ABANDONED OR PROPOSED INCINERATORS IN THE UNITED STATES

FIGURE NO. 4


FIXED CHARGES ARE BASED ON $2000 PER RATED TON OF CAPACITY.
INITIAL CONSTRUCTION COST, AMORTIZED OVER 20 YEARS AT A 3% INT. RATE.
$
COST PER TON
4.00
3.00
2.00
1.00
0
TOTAL COSTS
OPERATION AND MAINTAINANCE
FIXED CHARGES
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
TONNAGE INCINERATED DAILY
RATED CAPACITY — 200 TONS PER 24 HOURS

THE INFLUENCE OF PERCENTAGE UTILIZATION OF CAPACITY ON ESTIMATED COSTS FOR MUNICIPAL INCINERATION

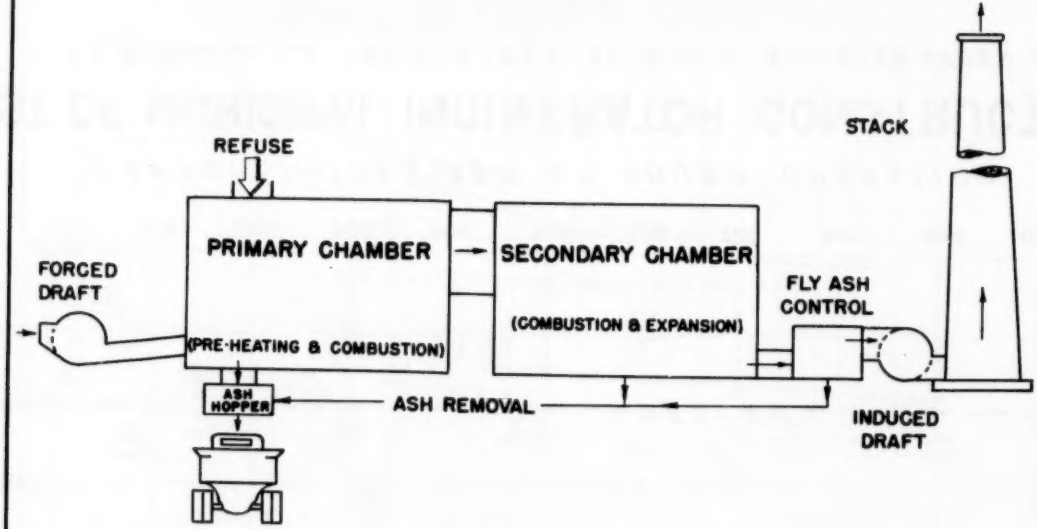
FIGURE NO. 5



COST OF MUNICIPAL INCINERATOR CONSTRUCTION

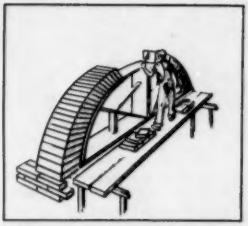
(REDUCED TO 1950 LEVEL BY E. N. R. BUILDING INDEX)

FIGURE NO. 6

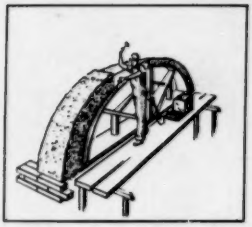


SCHEMATIC DRAWING OF AN INCINERATOR

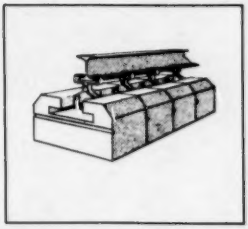
FIGURE NO. 7



ARCH BRICK CONSTRUCTION

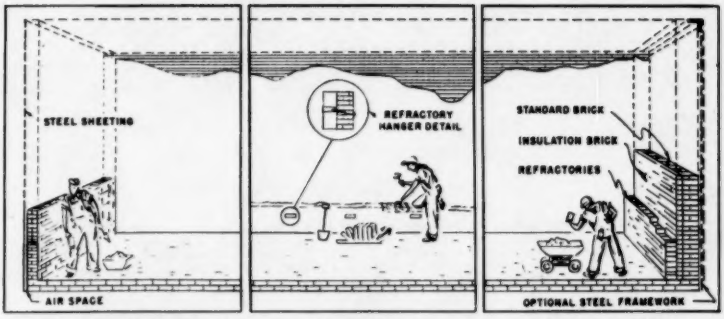


PLASTIC ARCH CONSTRUCTION



SUSPENDED OR FLAT ARCH CONSTRUCTION

CEILING CONSTRUCTION



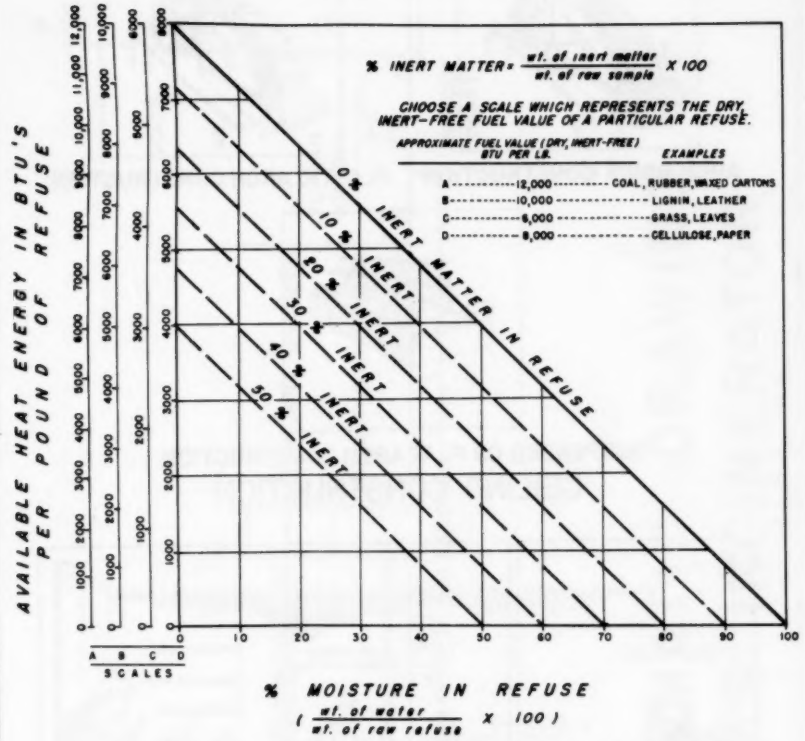
TROWELED BRICK CONSTRUCTION

PLASTIC CONSTRUCTION

DIPPED BRICK CONSTRUCTION

REFRACTORY CONSTRUCTION PRACTICES

FIGURE NO. 8


AVAILABLE HEAT ENERGY IN BTU'S PER POUND OF REFUSE
% INERT MATTER = wt. of inert matter / wt. of raw sample X 100
CHOOSE A SCALE WHICH REPRESENTS THE DRY, INERT-FREE FUEL VALUE OF A PARTICULAR REFUSE.
APPROXIMATE FUEL VALUE (DRY, INERT-FREE) BTU PER LB.
EXAMPLES
A ---------- 12,000 ---------- COAL, RUBBER, WAXED CARTONS
B ---------- 10,000 ---------- LIGNIN, LEATHER
C ---------- 6,000 ---------- GRASS, LEAVES
D ---------- 8,000 ---------- CELLULOSE, PAPER
0 % INERT MATTER IN REFUSE
10 % INERT
20 % INERT
30 % INERT
40 % INERT
50 % INERT
A B C D
SCALES
% MOISTURE IN REFUSE
(wt. of water / wt. of raw refuse X 100)

EXAMPLE: Colorimeter tests on a refuse sample show a dry, inert-free fuel value of 6,000 Btu per lb. Further analysis of the same sample indicates that 20% of the sample is inert and 30% is water. The point of intersection of the 30% moisture line and the 20% inert line is followed horizontally to the left, where on scale C (based on 6,000 Btu per lb.) is read the available heat energy: 3,000 Btu per lb.

RELATIONSHIP BETWEEN

HEAT ENERGY AND MOISTURE CONTENT

AS A FUNCTION OF THE INERT MATTER IN THE RAW REFUSE

FIGURE NO. 9